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Alpha and beta diversity and distribution pattern of millipedes (Myriapoda Diplopoda) along an altitudinal gradient in Southern Cameroon rainforest

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ABSTRACT Mountainous regions serve as critical ecosystems that promote endemism and serve as biodiversity hotspots, supporting a wide array of species, including millipedes. As one of the most important bioindicator groups, millipedes are particularly sensitive to habitat loss and tend to thrive in specific ecological niches. This study investigates the influence of altitudinal gradient on the community structure and assemblages of millipedes in southern Cameroon rainforest. Millipedes were sampled using a combination of pitfall traps, quadrat sampling, and litter sifting across three distinct elevational zones and vegetation types (0–400 m, 401–800 m, and 801–1200 m above sea level). A total of 994 individuals representing 71 species, 4 orders, 12 families, and 41 genera were recorded. The order Polydesmida was the most abundant and diverse (comprising 60.56% of the total sample and 35 species), followed by Spirostreptida (28.67% and 31 species) and Spirobolida (9.25% and 4 species). Cryptodesmidae was the most abundant family, while the least abundant was Spirostreptidae. The most abundant species was *Aporodesmus gabonicus* (29.38%), followed by *Kartinikus colonus* (7.75%) and *Aporodesmus falcatus* (5.73%). Along the altitudinal gradient, the millipede diversity increased slightly from lower level (H_1' = 1.32±0.15) (0-400 m asl) to transitional level (H_2' = 1.56±0.13) (401-800 m asl), and reached a maximum in upper level (H_3' = 1.98±0.18) (801 m to 1200 m asl). This distribution pattern of millipede in diversity suggests biotic homogenization as main factor leading to the weak dissimilarity of species between different altitudinal zones and the replacement of habitat specific species by opportunist or cosmopolitan species. This study provides valuable insights into the biogeography of millipede species along altitudinal gradients and offers essential information that could inform future conservation strategies aimed at preserving these sensitive ecosystems.

KEY WORDS Cameroon rainforest; diversity; distribution; elevation; millipedes.

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INTRODUCTION

Understanding the distribution patterns of biodiversity requires the study of spatial variation in its environment, which is essential in ecology and biogeography (Rosenzweig, 1995; Lomolino et al., 2010). 95% of experimental studies support a positive relationship between diversity and ecosystem functioning (Purvis & Hector, 2000; McCann, 2000; Irmler, 2000). Among these ecosystems, mountains are the great areas of biodiversity and high levels of endemism (Willig et al., 2003, Gradstein et al., 2008), as many invasive species find their way back into the wild (Colwell et al., 2008; Hoorn et al., 2018). They account for approximately 25% of the area of all terrestrial ecosystems (Miller & Spoolman, 2011). Indeed, mountain regions offer unique climatic conditions and soil quality that would favour biological invasions (Pauchard et al., 2016).

The study of altitudinal variation in species communities has long fascinated ecologists and biogeographers (Rhode, 1999). Relevant studies along elevational gradients have highlighted the importance of environmental factors such as temperature and moisture in shaping species distributions along elevational gradients (Whittaker, 1960), supported the hypothesis that high-altitude ecosystems are especially rich in species that are adapted to extreme conditions (Rahbek, 2005), provided evidence that ecological factors such as temperature, vegetation type, and habitat connectivity influence species distributions (Szewczyk & McCain, 2016), and emphasized the impact of human activities at lower altitudes and the strong climatic constraints at higher altitudes (Gallou et al., 2017). These elevational studies have identified four distinct patterns of species distribution: decreasing, low plateau, low plateau with a mid-peak and mid-elevation peak (McCain, 2009).

Diplopoda (millipedes) are one of the most significant components of soil macrofauna. They are found across a broad range of altitudinal and latitudinal environments. They typically inhabit specific niches, including forest litter, decaying wood, plant debris, and compost (Golovatch & Kime, 2009). Millipedes are the third most diverse group of terrestrial arthropods, following Insecta and Arachnida, with approximately 80,000 species or subspecies, of which over 12,000 have been described (Hoffman, 1980, 1982; Shelley, 2007; Brewer et al., 2012). They play an essential role in the decomposition of organic matter, ranking just behind earthworms and termites (Crawford, 1992). In tropical miombo forests, for example, their role in organic matter decomposition has been estimated at 30.6% of the annual litterfall (Dangerfield & Telford, 1989).

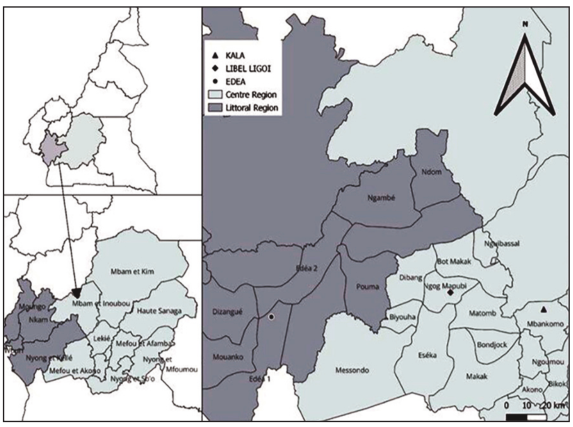

Figure 1. Map showing the location of the three selected altitudinal zones in the southern Cameroon rainforest.

While most altitudinal studies have focused on insect fauna, including butterflies (Gallou et al., 2017), ants (Szewczyk & McCain, 2016; Fisher & Robertson, 2002; Araujo & Fernandes, 2003; Bharti & Sharla, 2009), beetles (Jung et al., 2012), bees and wasps (Perillo et al., 2017), and termites (Ratiknyo et al., 2018), relatively few studies have investigated the altitudinal distribution of Myriapoda fauna, particularly in tropical regions. Most existing studies have been conducted in temperate climates (Hamer & Slotow, 2009; Gilgado et al., 2022). In contrast, the diversity patterns of millipede species in tropical ecosystems remain poorly understood (Mbenoun et al., 2019).

This study aims to address this gap by examining the influence of altitudinal gradients on species richness, diversity, abundance, composition, and distribution of millipedes across three altitudinal zones, extending from the coastal region to the central regions of Cameroon. We hypothesize that both species diversity and distribution of millipedes are significantly impacted by anthropogenic pressures, not only at lower altitudes but also at higher elevations.

MATERIAL AND METHODS

Study area

This study was carried out from November 2022 to January 2024 in the southern Cameroon rainforest (Fig. 1). The inventories were conducted from coastal to high altitude regions of Cameroon to the three following selected sites.

Kala (801–1200 m asl, 3°50’N - 11°21’E, altitude 954 m asl), is situated southwest of Yaounde, center region of Cameroon. The global vegetation of Kala is dominated by the semi-deciduous, hygromesophilic and montane forest. (Achoundong , 996; Madiapevo et al., 2017) The rainfall pattern is bimodal with two rainy seasons and two dry seasons. The mean air temperature ranges from 19.2 °C to 28.6 °C.

Libel-Lingoï (401–800 m asl, 3°54.210'N - 10°55.610'E, altitude 455 m asl) is situated in Center region of Cameroon. The vegetation of Libel Lingoï is dominated by Atlantic Forest Green; annual precipitation is over 2100 mm; the average air temperature is 23°C to 24°C (Kanmegne et al., 2006).

Edea (0–400 m asl, 3°48'N - 10°08'E, altitude 88 m asl) is located in littoral region of Cameroon; The rainfall pattern is unimodal with two seasons (one long rainy season and one short dry season). The climate is markedly more humid, due to the prevalence of precipitation (Sighomnou, 2004). The vegetation is dominated by Atlantic evergreen rainforest with an average temperature of 27°C (Feka et al., 2009).

Sampling processing

Within each elevation, millipedes were surveyed using hand collection, pitfall trapping and Winkler extraction. These sampling methods were implemented along the three parallel transects (110 m length and 2 m width each) spaced 10 m apart. Fifteen sampling events were conducted at each altitudinal level, yielding a total of 450 samples per elevation (1 site x 10 samples x 3 methods x 15 replicates):

Hand collection. Ten 3 m^2 quadrats were set along the first transect. Two consecutive quadrats were 10 m apart and 10 m from the nearest pitfall trap. Within each elevation, millipedes were searched actively in rotten logs and stumps, under stones, bark, layers of leaf litter and directly in the soil during 15 minutes of active searching. A total of 150 quadrats (1 site × 15 replicates × 10 sampling points) were sampled at each elevation.

Pitfall trapping. Pitfall traps made up of plastic drinking cups (85 mm top diameter) were placed on a buried section of a PVC pipe so that the rim of the cup was flush with the ground surface. Ten traps were set along the second transect and half filled with ethylene-glycol (75%) as preservative. Traps were separated by 10 m giving a total of 150 pitfall traps (1 site x 15 replicates x 10 sampling points) for each elevation. Each pitfall was covered by an aluminum roof to prevent rainfall from getting into the traps. Specimens were collected after seven days and stored in 70% ethanol.

Litter sifting. Ten 1 m^2 samples of leaf litter were sifted to remove large leaves, stones and plastic waste. Leaf litter samples were collected near cacao plantation and in old fallow. A total of 150 samples of leaf litter were sampled at each elevation. The sifted litter was then placed in mini-Winkler sacks for 48 hours. During this time, millepedes and other invertebrates from within the litter sample migrated out of the litter, as a behavioural response to disturbance of their habitat and eventually fell into a container filled with 70% ethanol.

All millipedes were collected with forceps or by hands and preserved in labelled vials containing 70% ethanol. Each specimen was then photographed, dissected (only diplopod species) and identified at the family, genus and species levels or assigned to morphospecies with the help of relevant dichotomous keys available in the literature (Kraus, 1960, 1966; Demange & Mauriès, 1975; Krabbe, 1982; Hoffman et al., 1996; Hamer, 1999; Minelli, 2011, 2015). Voucher specimens were deposited in the reference collections of the Laboratory of Zoology at the University of Yaounde.

Data analysis

Data from all sampling methods were pooled at each site and entered into a matrix in the form of presence-absence data before analysis. We used the total occurrence of a species in all samples as an estimate of the relative abundance of that species across all altitudes (Dajoz, 1982). To estimate maximum species richness and sampling effort, EstimateS software (Colwell 2006) was used to calculate eight relevant estimators with 100 permutations: Incidence-based coverage estimator ICE 1&2, Chao 1&2, Jacknife 1&2, Bootstrap and MMMeans, Chao (1987), Chao & Lee (1992), Colwell & Coddington (1994), Longino (2000), and Marcon (2016). To assess survey completeness for each elevation zone, species accumulation curves were plotted as a function of number of samples. Alpha diversity was estimated using the Shannon-Wiener index (H′), Pielou's evenness index (J) (Pielou, 1969) and the Berger-Parker dominance index (D) (Cheng, 2004). The Kruskal-Wallis test was used to compare the diversity indices between different sites. We also used the beta diversity index (Bray-Curtis distances) to visualize differences in community turnover between altitudes.

RESULTS

Overall taxonomic composition

A total of 994 individuals, representing 71 species from 41 genera, 12 families and four orders (Polydesmida, Spirostreptida, Spirobolida and Stemmiulida) was recorded from all three sites sampled (Table 1). Polydesmida was the most abundant order (60.56%), followed by Spirostreptida (28.67%) and Spirobolida (9.25%). Spirostreptidae (with 21 species and 11 genera) was the most diverse family followed by Chelodesmidae (12 species and seven genera) and odontopygidae (10 species and seven genera). The most abundant species was *Aporodesmus gabonicus* (29.38%), followed by *Kartinikus colonus* (7.75%) and *Aporodesmus falcatus* (5.73%).

Regarding each elevation, *Aporodesmus gabonicus* was the most abundant with 21.21% of individuals, followed by *Coenobothrus* sp.1 (15.91%) and Spirostreptidae gen.3 sp.1 (7.58%) at 0–400 m asl. Between 401–800 m asl, *Neocordyloporus aubryi* was the most abundant with 20.65% of individuals, followed by *Paracordyloporus porati* (13.55%) and *Kartinikus colonus* (6.45%). Between 801–1200 m asl, *Aporodesmus gabonicus* was the most abundant with 39.32% of individuals followed by *Kartinikus colonus* (8.2%) and *Aporodesmus falcatus* (6.93%) (Table 2).

Estimates of species richness and sampling efficiency

The eight non-parametric estimators of species richness (ACE, ICE, Chao1, Chao2, Jacknife1, Jacknife2, Boostrap and MMMeans) showed an average sampling efficiency above 70% in the three sites (Table 3). The non-parametric estimator Boostrap was the most efficient on average in the three altitudinal levels combined with a value of over 85%, followed by Chao1 with 84.31%. The species accumulation curve in each zonation was still rising indicating additional sampling effort (Fig. 2). In addition, the accumulative curves showed that the

Orders	Families	Genera	Species
Polydesmida	Chelodesmidae	7 (17.07)	12 (16.90)
	Cryptodesmidae	2 (4.87)	6 (8.45)
	Gomphodesmidae	3 (7.31)	4 (5.63)
	Haplodesmidae	1 (2.43)	1 (1.4)
	Oxydesmidae	3 (7.31)	5 (7.04)
	Paradoxosomatidae	1 (2.43)	4 (5.63)
	Pyrgodesmidae	2 (4.87)	3 (4.22)
Spirostreptida	Spirostreptidae	11 (26.82)	21 (29.57)
	Odontopygidae	7 (17.07)	10 (14.08)
Spirobolida	Pachybolidae	2 (4.87)	2 (2.81)
	Trigoniulidae	1 (2.43)	2 (2.81)
Stemmiulida	Stemmiulidae	1 (2.43)	1 (1.4)
Total		**41**	**71**

Table 1. Taxonomic distribution of the number of families, genera and species millipedes collected from 2022 to 2023. Proportions are given in parentheses.

quadrat was the most effective method while the Winkler method was the least effective, with 14 species collected (Fig. 3).

Abundance and diversity of millepedes

The abundance of species at each elevation showed the similar elevational patterns to those observed in species richness. The maximum abundance of species was recorded between 801–1200 m asl (707 specimens) whereas the minimum was observed between 0–400 m asl (132 specimens). Both species richness and abundance showed a significant different across different elevations (Kruskal Wallis H=17.79, ddl=2, $p < 0.05$ and H=21.21, ddl=2, $p < 0.05$ respectively) (Table 4). The mid-elevation was more diversified (H=2.93) than the lower (H=2.91) and the upper elevations (H=2.49) elevations. The highest values of Simpson, Evenness and Berger-Parker indices observed at different elevations suggested dominance by *Aporodesmus gabonicus* (Table 4).

Species turnover and distribution pattern

Overall, the diplopod species turnover (Bray Curtis dissimilarity) was high between different elevations (Fig. 4). Elevations 0–400 and 401–800 m asl formed a first cluster distinct from the second cluster (801–1200 m asl). The average values of Species richness, Simpson and Shannon decreased at lower elevations (0–400 m asl), increased slightly at mid -elevations (401–800 m asl) and reached a maximum value at upper elevations (801–1200 m asl) (Fig. 5).

DISCUSSION

This study showed that millipede species along an altitudinal gradient in southern Cameroon rainforest are diverse and abundant. A total of 71 millipede species or morpho-species were recorded along the three studied elevations. Species richness was higher than that found in Campo Ma'an National Park by Mbenoun et al. (2017), and in the Douala-Edéa National Park by Nzoko Fiemapong et al. (2023) in Cameroon. In addition, the present number of millipede species was high compared to that recorded five years ago at Mount Kala, Centre Cameroon (49 species) (Mbenoun Masse & Makon, 2019), and other studies conducted at high altitude in South Africa (51 species) (Hamer & Slotow, 2009). These findings confirmed the assertion according to which mountainous areas are hotspots of biodiversity and endemism (Hofer, 2005; Kollmair et al., 2005). The reason of this high species richness recorded may be due to a variety of ecological conditions, rainfall regime, semi-deciduous forest type and temperature variation in elevation areas that are favorable to millipede development and survival. Consistently, Bogyó et al. (2015) and Topp et al. (2006) highlighted that the occurrence of millipedes depends on the type of ecosystem, soil moisture, humidity high and the presence of microhabitat such as dead wood.

The present study showed that the Spirostreptida was among the most species rich millipede order. These results are consistent with that found at Mount Kala (Mbenoun Masse & Makon, 2019). According to Enghoff et al. (2015), this group is the most dominant in almost all terrestrial environment

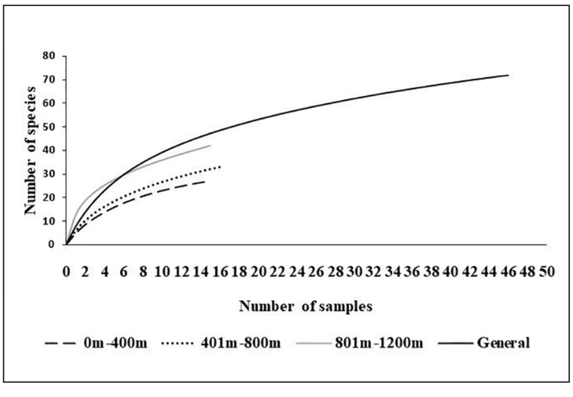

Figure 2. Sample-based accumulation of millipede species richness at the three elevations.

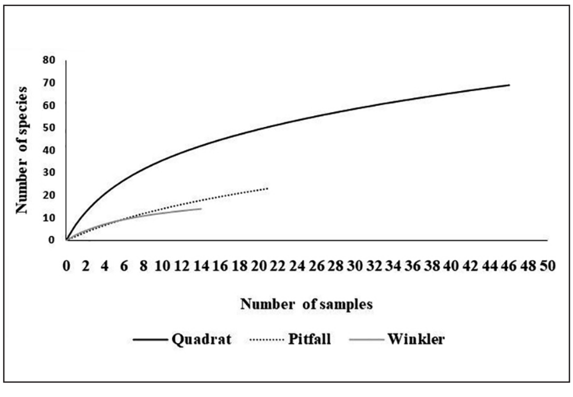

Figure 3. Accumulative curve of species according efficiency sampling methods.

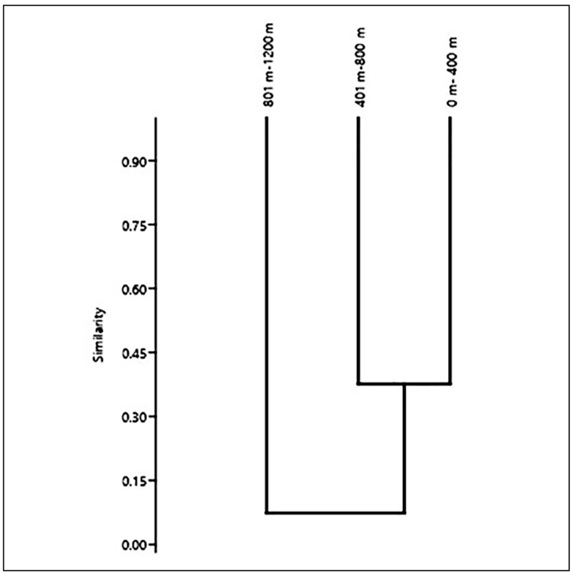

Figure 4. Cluster analysis of millipede species turnover at the various elevations based on the Bray–Curtis index.

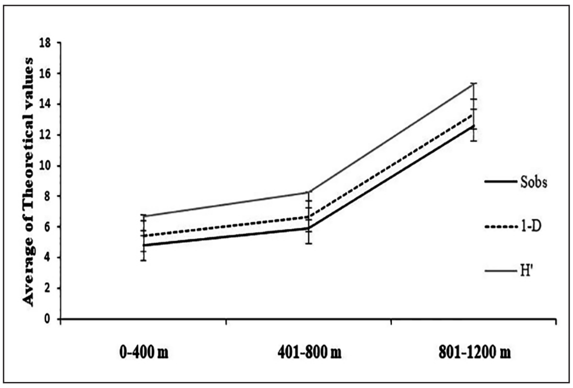

Figure 5. Average of theoretical values associated standard error of species richness, Simpson and Shannon-Wiener indices within different elevations.

except Antarctic zoogeographical regions within Juliformia. Furthermore, Spirostreptidae was the most species-rich millipede family found at different elevations, while Odontopygidae was the most dominant family at Mount Kala (Mbenoun et al., 2017) and Chelodesmidae in Douala-National Park (Nzoko Fiemapong et al., 2023). The Spirostreptida group is one of the largest millipede family's endemic to the Afrotropical region, made up of several families such as Odontopygidae and Spirostreptidae and prefer the higher altitude environments (Enghoff et al., 2015; Enghoff, 2016)

The species *Aporodesmus gabonicus* and *Kartinikus colonus* were the most abundant in our study. *Aporodesmus gabonicus* occurs in the wide arrays in Cameroon, and its numerical dominance has previously been reported in Campo'o Park and at Mount Kala (Mbenoun et al., 2017; Mbenoun & Makon, 2019). It is considered as one of the most widespread species of the family Cryptodesmidae in West and Central Africa. (Mauries, 1968; Hoffman, 1972). *Kartinikus colonus* was recorded as the most abundant in Kirimiri forest in Kenya by Omondi et al. (2020) and in Douala-Edea Park National (Nzoko Fiemapong et al., 2023). This species is regarded as a generalist or cosmopolitan species which is able to found in several habitats. In fact, Block & Brennen (1993) underlined that some species can be found in several habitat or to tolerate unfavorable habitat changes because of the modification of their physiology to reduced food source, increased water loss and niche heterogeneity.

The mean sampling success was above 70% in all combined sites. The performance of most of the estimates ranged between 56.96% and 92% of the sampling success. The highest efficiency values were obtained with Chao between 0–400 m and the lowest with Chao2 between 401–800 m asl. The boostrap and Chao1 estimator mean was the most efficiency for all combined sites. The Boostrap (Efron, 1979) is one of the best species richness estimators, it is fully automatic, requires no theoretical calculations and is not based on asymptotic results (Colwell & Coddington, 1994). Quadrat sampling was the most efficient compared to other methods. This result was consistent with that obtained by Nzoko Fiemapong (2020). The quadrat sampling appears to be one of the most widely and efficiency method for collecting soil invertebrates (Zaller et al., 2015), especially millepedes. The randomized species accumulation curves of the three sites were still increasing towards the end of the sampling period. This suggests that additional sampling effort is required to reach an asymptotic plateau.

Considering species richness and abundance turnover, different elevations had a weak dissimilarity even through elevations between 0–400 m to 401–800 m asl formed a single cluster. According to McCain & Grytnes (2010) mountain regions exhibit climatic conditions such as elevated humidity and

ORDERS-FAMILIES-SPECIES	**0-400 m**	**401-800 m**	**801-1200 m**
POLYDESMIDA	56.82	69.03	59.41
CHELODESMIDAE	13.64	49.03	0.99
Anisodesmus erythropus (Lucas, 1858)	0.76	-	-
Anisodesmus sp.1	0.76	3.87	-
Chelodesmidae gen.1 sp.1	-	-	0.14
Chelodesmidae gen.2 sp.1	5.30	5.81	-
Diaphorodesmus dorsicornis (Porat, 1894)	1.52	3.23	0.14
Diaphorodesmus sp.1	-	-	0.14
Diaphorodesmus sp.2	-	-	0.14
Kyphopyge sp.	-	-	0.14
Neocordyloporus aubryi (Lucas, 1858)	3.03	20.65	-
Paracordyloporus porati (Carl, 1905)	0.76	13.55	0.28
Paracordyloporus sp.1	1.52	-	-
Paracordyloporus sp.2	-	1.94	-
CRYPTODESMIDAE	25.76	9.03	49.50
Aporodesmus falcatus Porat, 1894	4.55	1.29	6,93
Aporodesmus gabonicus (Lucas, 1858)	21.21	5.16	39.32
Aporodesmus sp.1	-	-	0.99
Aporodesmus sp.2	-	1.94	-
Aporodesmus sp.3	-	0.65	-
Tanydesmus ordinatus (Cook, 1896)	-	-	2.26
GOMPHODESMIDAE	6.82	-	3.11
Gomphodesmidae gen.1 sp.1	3.03	-	-
Gomphodesmidae gen.2 sp.1	1.52	-	-
Tymbodesmus golovatchi Nzoko Fiemapong et Van-denSpiegel, 2017	-	-	3.11
Tymbodesmus sp.	2.27	-	-
HAPLODESMIDAE	2.27	0.65	-
Cylindrodesmus hirsutus Pocock, 1889	2.27	0.65	-
OXYDESMIDAE	4.58	2.58	0.28
Coromus sp.1	-	-	0.14
Coromus sp.2	-	1.94	0.14
Coromus sp.3	2.27	1.94	-
Crystallomus sp.	0.76	-	-
Oxydesmidae gen.2 sp.1	1.52	-	-
PARADOXOSOMATIDAE	3.79	6.45	3.68
Duseviulisoma porati Mauriès, 1967	-	-	0.28

Scolodesmus sp.1	-	-	3.39
Scolodesmus sp.2	3.79	5.81	-
Scolodesmus sp.3	-	0.65	-
PYRGODESMIDAE	-	1.29	1.84
Monachodesmus armorum Golovatch, 2015	-	0.65	0.14
Urodesmus camerunensis Golovatch, 2015	-	-	0.57
Urodesmus cornutus Golovatch, 2015	-	0.65	1.13
SPIROBOLIDA	-	1.94	13.15
PACHYBOLIDAE	-	-	8.63
Amblybolus sp.	-	-	6.08
Pelmatojulus excisus (Cook, 1897)	-	-	2.55
TRIGONIULIDAE	-	1.94	4.53
Thrinciulus laevicolis Porat, 1894	-	1.29	4.53
Thrinciulus sp.	-	0.65	-
SPIROSTREPTIDA	49.18	29.03	25.88
ODONTOPYGIDAE	22.73	10.97	8.35
Coenobothrus bipartitus (Porat, 1894)	0.76	1.29	3.25
Coenobothrus detruncatus (Porat, 1894)	-	-	2.83
Coenobothrus sp.1	15.91	1.29	-
Odontopyge bipartita Porat, 1894	-	1,29	-
Odontopygidae gen.1 sp.1	-	-	0,14
Odontopygidae gen.2 sp.1	3.03	0.65	-
Odontopygidae gen.3 sp.1	-	5.16	-
Odontopygidae gen.4 sp.1	3.03	1.29	-
Peridontopyge sp.	-	-	1.84
Peridontopyge trauni Silvestri, 1907	-	-	0.28
SPIROSTREPTIDAE	20.45	18.06	17.54
Analocostreptus amandus (Attems, 1914)	-	-	0.28
Gymnostreptus madegama (Demange, 1957)	-	-	0.28
Gymnostreptus sp.	-	-	0.85
Gymnostreptus striolatus (Jeeckel, 2002)	-	-	0.14
Kartinikus colonus Attems, 1914	6.82	6.45	8.20
Kartinikus laevis (Voges, 1878)	1.52	1.94	-
Odontostreptus sjostedti Krabbe, 1982	-	-	0.71
Onychostreptus aoutii Demange, 1971	-	-	0.14
Onychostreptus assiniensis (Attems, 1914)	-	-	0.14
Spirostreptidae gen.1 sp.1	-	1.29	3.39

Spirostreptidae gen.2 sp.1	2.27	-	-
Spirostreptidae gen.3 sp.1	7.58	1.94	-
Spirostreptidae gen.4 sp.1	-	1.29	-
Telodeinopus canaliculatus (Porat, 1894)	1.52	3.23	0.42
Telodeinopus sp.1	-	-	0.71
Telodeinopus sulcatus (Voges, 1878)	-	0.65	-
Aprosphylostreptus carinatus (Porat, 1893)	-	1.29	1.84
Aprosphylostreptus propinquus (Porat, 1893)	-	-	0.14
Urotropis sp.1	0.76	-	-
Urotropis sp.2	-	-	0.14
Aprosphylostreptus trispinus (Demange et Mauries, 1975)	-	-	0.14
STEMMIULIDA	-	-	-
STEMMIULIDAE	-	-	-
Stemmiulus nigricollis (Porat, 1894)	-	-	1.56
TOTAL	**100**	**100**	**100**

Table 2. Relative abundances (%) of millipede species along different elevations in southern Cameroon rainforest.

temperatures cooling, that are markedly disparate from those observed in other terrestrial areas, and these conditions influence species richness and shape species distributions along elevational gradients (Rahbek, 1995). Therefore, the elevational areas with their specific environmental conditions, might be favorable to the survival of hygrophilous species such as diplopods (Minelli & Golovatch, 2013).

The species richness and diversity indices increased from lower to mid-elevation level and reached a maximum value at the upper elevations. This distribution pattern is similar to that proposed by McCain (2009). Two main factors are proposed to explain that: anthropogenic activities pressure and the abiotic factors. Indeed, anthropogenic modifications through the conversion of natural habitat to build habitats or agriculture is recognized as detrimental to biodiversity, threatening native fauna diversity and leading to biotic homogenization. Interestingly, effect of anthropogenic modifications on homogenization has been demonstrated on others taxa like ant species in the same geographical region (Mbenoun et al., 2021). It has largely been reported that habitat changes can influence the distribution of species in an environment (Hopkin & Read, 1992; David, 2015; Rodrigues et al., 2017; Sklodowski & Tracz, 2018). The change in land-use from native forests to exotic forest plantations is responsible for modifications to the taxonomic composition of macroinvertebrate assemblages, with greater species richness and abundances in native forest catchments versus exotic forest plantations catchments (Fierro et al., 2016). Likewise, Hopkin & Read (1992) and Bogyó et al. (2015) reported that the occurrence of millipede species in forest habitats, is closely related to the high relative humidity and the availability of leaf litter.

CONCLUSIONS

The present study shows the diversity and distribution pattern of millipede species along an altitudinal gradient from coastal to highland regions of Cameroon. Species richness and abundant were higher than those obtained in the similar studies conducted in this region. Despite a significant different in diversity indices, the similarity was high between elevation levels. Species richness and diversity increased from lower to upper elevation lev-

Non parameters indices	0–400 m	401–800 m	801–1200 m	Means
ACE	31.14 (86.70)	41.24 (72.44)	65.76 (63.86)	46.04 (74.33)
ICE	37.8 (71.42)	50.69 (65.65)	63.97 (65.65)	50.82 (67.57)
Chao1	29.31 (92.11)	36.58 (90.21)	59.48 (70.61)	41.79 (84.31)
Chao2	32.25 (83.72)	42.48 (77.68)	73.73 (56.96)	49.48 (72.78)
Jacknife1	36.33 (74.31)	46.13 (71.53)	57.87 (72.57)	46.77 (72.80)
Jacknife2	39.37 (68.58)	51.84 (63.65)	70.19 (59.83)	53.8 (64.02)
Boostrap	31.51 (85.68)	39.02 (84.57)	48.58 (86.45)	39.70 (85.56)
MMMeans	39.93 (67.61)	46.08 (71.61)	47.18 (89.02)	44.39 (76.08)
Means	34.7 (77.80)	44.21 (72.38)	60.84 (70.62)	46.53 (73.66)

Table 3. Observed species richness (Sobs) and expected number of species, as calculated with four species richness estimators. The sampling success given as proportion of species observed to the estimated species numbers are given in parentheses.

Diversity alpha	0–400 m	401–800 m	801–1200 m	H	Ddf	P
Sobs	27 (4.8±0.64)a	33 (5.93±0.56)a	42 (12.6±1.04)b	17.79	2	<0.05
Specimens	132 (8.8±1.59)a	155 (9.68±1.41)a	707 (47.13±9.17)b	21.21	2	<0.05
Simpson 1-D	0.9 (0.6±0.08)a	0.92 (0.74±0.05)b	0.82 (0.75±0.06)b	8.07	2	<0.05
H'	2.91 (1.32±0.15)a	2.93 (1.56±0.13)a	2.49 (1.98±0.18)b	11.63	2	<0.05
J (Pielou)	0.85 (0.74±0.07)a	0.84 (0.88±0.06)b	0.66 (0.79±0.05)a	6.70	2	<0.05
D	0.21 (0.42±0.09)a	0.21 (0.34±0.04)a	0.39 (0.22±0.06)b	13.2	2	<0.05
Hmax	3.29 (1.36±0.19)a	3.49 (1.66±0.14)a	3.73 (2.45±0.2)b	18.14	2	<0.05

Table 4. Diversity indices as a function of elevations and a one-way ANOVA parametric test. Mean ± SE are given in parentheses. Lower case: comparison between lines with Mann Witney post hoc test.

els. Biotic homogenization and the absence of mid-elevation effects at mid-elevation and climatic constraints at upper elevation due to anthropogenic activities correspond to the replacement of habitat specialist species by generalist or cosmopolitan species like *Aporodesmus gabonicus* and *Kartinitus colonus*. These species can quickly acclimate, adapt, disperse or change their behaviour in human-modified ecosystems. Consequently, *Aporodesmus gabonicus* and *Kartinitus colonus* species may be used as bio-indicator species for disturbance area and in the studies of environmental impact.

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